EL Program: **Sustainable Engineered Materials**

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Strategic Goal: Sustainable and Energy-Efficient Manufacturing, Materials, and Infrastructure

Summary: The standards used to classify and specify materials used in infrastructure, construction, and manufacturing are not able to ensure sustainable performance for the materials, because they are not adequately based on a measurement science foundation that addresses essential materials issues. This materials program approaches the solution of this problem from the perspective of service life prediction, a crucial sustainability metric, and applies this concept to polymer composites and concrete. These two material thrusts will develop measurement science composed of a combination of characterization, performance measurement, accelerated durability tests, and modeling to develop standards that will be used by industry and specified by end-users in these broad application areas to enable service life prediction and thus help to ensure sustainable materials performance.

Objective: To develop and deploy advances in measurement science for sustainable materials used in manufacturing and construction, including cementitious and polymer composite materials, by 2016.

What is the problem? *The standards used to classify and specify materials used in infrastructure and manufacturing are not able to ensure sustainable performance for the materials, because they are not adequately based on a measurement science foundation that addresses essential materials issues and enables service life prediction*. The main material classes that are common to the industry sectors mentioned above are steel, concrete, and polymer composites. This program will focus on concrete and polymer composites. However, essentially all exposed steel is protected by a corrosion barrier, which is usually a filled polymer coating or concrete, so that this program's results will also directly affect the sustainable use of steel.

Figure 1 below shows six sequential stages of the material sustainability cycle (MSC)[1]. Between each sequential pair, standards are needed to effectively communicate from one stage to the next. Standards act like a Rosetta Stone ensuring that all parties understand and agree to generated information, the protocols and technical/scientific basis used to generate data, and data accuracy and precision. The standards that link across different elements are often the same – products are manufactured to meet certain engineered performance standards, which are the same standards used by specifiers, designers, and engineers. Therefore, multiple industrial sectors are stakeholders in this research.

The consequences of not having service life prediction capability for these materials are manifold. The total costs of repairing/replacing the US infrastructure is estimated to exceed \$2 trillion[2,3], and the American Society of Civil Engineers (ASCE) has recommended that "as infrastructure is built or rehabilitated, life cycle cost analysis should be performed"[4], which necessitates service life prediction. The Administration has stated that building a world-class physical infrastructure is one of its top priorities for innovation[5,6]. A technology gap in the long-term strategic plan for highways is an inability to ensure sustainable performance of concrete in the short and long term[7]. Service life prediction of polymer composites have been clearly seen as a major national need[8,9]. The Administration's *Blueprint for a Clean Energy Future* [10] calls for the development of more efficient cars and trucks by making investments in polymer composites for lightweighting. New, nano-enabled fiber-reinforced polymer composites can help rejuvenate

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1 BEES (Building for Environmental and Economic Sustainability),http://www.nist.gov/el/economics/BEESSoftware.cfm

2 *Report Card for America's Infrastructure*, American Society of Civil Engineers, 2009. (www.asce.org)

3 *Investment in Federal Facilities*, National Research Council (2006).

4 ASCE 2009 Infrastructure Report Card (http://www.infrastructurereportcard.org)

5 *A Strategy for American Innovation: Driving Towards Sustainable Growth and Quality Jobs*, http://www.whitehouse.gov/administration/eop/nec/StrategyforAmericanInnovation/

6 *OSTP/OMB Science and Technology Priorities for the FY 2012 Budget*, 2010, http://www.whitehouse.gov/sites/default/files/microsites/ostp/fy12-budget-guidance-memo.pdf

7 "Highways of the Future – A Strategic Plan for Highway Infrastructure Research and Development," FHWA-HRT-08-068, Federal Highway Administration (July 2008)

8 *Going to Extremes: Meeting the Emerging Demand for Durable Polymer Matrix Composites*, Committee on Durability/Life Prediction of Polymer Matrix Composites in Extreme Environments, National Research Council, 2005.

9 Vision 2020 Chemical Industry of The Future: Technology Roadmap for Materials: http://www.chemicalvision2020.org/pdfs/materials_tech_roadmap.pdf

10 *Blueprint For a Clean Energy Future,* http://www.whtehouse.gov/sites/default/files/blueprint_secure_energy_future.pdf

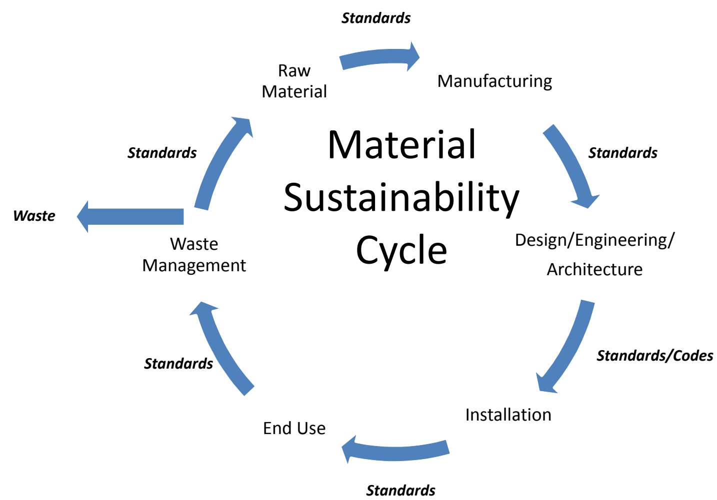

Figure 1: Illustration of the sustainability cycle for materials in the US

US manufacturing, but the lack of service life prediction capability for this class of materials was a barrier identified by industry to their widespread use[11]. The addition of nano-fillers to polymeric matrices greatly improves product performance, but has raised environmental, health and safety issues with the release of these nanoparticles over time.[12,13] The durability of filled polymers, which are non-structural polymer composites, plays a key role in important national problems. Plastic piping is expected to be used in increasing volumes as replacements, as pipe leaks and breaks in municipal water/sewage systems have steadily increased in recent years[14]. The yearly global market in sealants and adhesives is approximately $40B, and having standards that accurately measure their durability is an outstanding problem in their sustainable use [15]. The aging of polymeric electric cable insulation in nuclear power plants is a national problem, affecting all of the existing fleet of 104 US nuclear reactors[16].

Why is it hard to solve? Polymer composites and concrete are inherently complex, multi-phase systems. Both are made from a variety of feedstocks, including industrial by-product materials. Unexpected variations in performance mandate that careful material characterization must take place, complicated by the multi-phase nature of these materials. Specifying short term properties is hard since not all the required measurement techniques have been developed or standardized, and these properties are often time and environment-dependent. The degradation of these

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[11] The New Steel? Enabling the Carbon Nanomaterials Revolution: Markets, Metrology and Scale-Up http://www.nist.gov/cnst/thenewsteel.cfm

[12] Congressional Research Service, Nanotechnology and Environmental, Health, and Safety: Issues for Consideration, John F. Sargent Jr., January 20, 2011, *http://www.fas.org/sgp/crs/misc/RL34614.pdf*.

[13] *A Research Strategy for Environmental, Health, and Safety Aspects of Engineered Nanomaterials* (2011), Committee to Develop a Research Strategy for Environmental, Health, and Safety Aspects of Engineered Nanomaterials; National Research Council

[14] *Sustainable water infrastructure*, US Environmental Protection Agency, http://water.epa.gov/infrastructure/sustain/index.cfm

[15] ASTM and RILEM, Durability of Building and Construction Sealants and Adhesives, STP 1514 (2010).

[16] Essential Elements of an Electric Cable Condition Monitoring Program US NRC NUREG/CR-7000 BNL-NUREG-90318-2009 (http://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr7000/cr7000.pdf)

systems over their expected service life involves numerous component and environmental interactions and chemical, physical, and mechanical responses that operate over wide length and time scales, making long-term prediction difficult.

How is it solved today, and by whom? The measurement science problems that need to be solved in order to have measurement science-based standards that can be used to support service life prediction for materials used in infrastructure and manufacturing have not currently been solved. For concrete, industry practice documents like ACI-365.1R-00[17] and certain computer models like Life-365[18] are guides and tools for estimating service life based on an over-simplified scientific basis. More comprehensive service life computer models, such as STADIUM[19] in Canada, do exist but in all cases, the initial condition is a properly placed, finished, and cured concrete element, which assumes adequate early-age performance[20]. The MIT Concrete Sustainability Hub, funded by the cement and concrete industry, is the major US academic player in modeling concrete sustainability and program collaboration with the Hub has already begun. The Nanocem consortium in Europe is active in service life of concrete issues, and the cement industry in Europe and Japan is active in the Cement Sustainability Initiative.

US industry relies on qualitative, long-term field exposure tests for service life prediction of polymer composites but the ability to generate repeatable and reproducible results has been a major weakness of this methodology. Underwriter's Laboratories uses its thermal aging test, UL 746B, to approve 20B polymer products per year, but does not take into account the effects of relative humidity, radiation, and mechanical load. There academic centers and industrial labs working in polymer nanocomposites, but not typically in service life prediction issues. The European Union and European industry funds research in the modeling and manufacture of nano-enabled fiber-reinforced polymer composites.

Why NIST? Measurement science research that results in standards used to classify and specify materials used in infrastructure, construction, and manufacturing is closely aligned with the NIST Engineering Laboratory (EL) Strategic Goal of Sustainable and Energy-Efficient Manufacturing, Materials, and Infrastructure. This program supports EL's mission[21], follows EL's vision[22], and relies on one of the EL core competencies[23] of durability and service life prediction of materials. NIST/EL is internationally known for the assessment of performance, durability and service life prediction of polymer composites and concrete, and has the

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[17] "Service Life Prediction – State-of-the-Art Report," ACI 365.1R-00, American Concrete Institute
[18] http://www.life-365.org
[19] http://www.simcotechnologies.com/Stadium/Introduction.aspx
[20] "Measurement Science Roadmap for Workability of Cementitious Materials" held at NIST on March 18, 2011 – NIST Technical note under review
[21] EL's mission is "To promote U.S. innovation and industrial competitiveness in areas of critical national priority by anticipating and meeting the measurement science and standards needs for technology-intensive manufacturing, construction, and cyber-physical systems in ways that enhance economic prosperity and improve the quality of life."
[22] EL's vision is "To be the source for creating critical solution-enabling measurement science, and critical technical contributions underpinning emerging standards, codes, and regulations that are used by the U.S. manufacturing, construction, and infrastructure industries to strengthen leadership in domestic and international markets."
[23] EL core competencies: Intelligent sensing, control, processes, and automation for cyber-physical systems; Systems integration, engineering, and processes for cyber-physical systems; Energy efficient and intelligent operation of buildings with healthy indoor environments; Sustainability, durability and service life prediction of building and infrastructure materials; Fire protection and fire dynamics within buildings and communities; Resilience and reliability of structures under multi-hazards.

instrumentation, computer hardware and software, and expert personnel to be able to carry out this program. Industry stakeholders have recognized this as evidenced by their willingness to partner with the program in various consortia and road mapping activities. State and federal agencies partner with NIST/EL by using the program's unique measurement science and services capabilities to support their mission/agency goals.

What is the new technical idea? The new technical idea is to couple advances in analytical instrumentation, controlled multi-factor exposure in the laboratory, and computational materials science to measure and predict the service life performance of materials to enable critical and sustainable end-use applications in infrastructure and manufacturing. This integrated approach will allow the measurement science to be developed that will provide the technical basis for new and improved standards that will support service life prediction for these complex materials.

Why can we succeed now? Large volumes of polymer composite and cementitious materials are consumed each year in infrastructure and manufactured product applications (e.g. aerospace and automotive). Engineers and designers regularly push the design limits of materials, such as in nano-filled polymers, nano-enabled fiber reinforced polymer composites, and increasing use of industrial by-products in concrete, which forces changes in existing standards and codes to enable sustainable use.

Significant advances have occurred in recent years in analytical instrumentation, the ability to control exposure environments, and software and hardware for modeling material performance. NIST has, by far, one of the largest and most specialized collections of instruments in the world for characterizing material degradation. NIST has pioneered the modeling of material properties and degradation processes and has the joint expertise to solve the hard problems associated with service life prediction and sustainable material performance.

NIST has strong partnerships with industry and the standards community. NIST's participation, and in many cases leadership, in technical standards committees coupled with active end-user engagement via consortia and road mapping workshops ensures that its technical ability to meet measurement science needs will result in effective technology transfer to industrial end-users via new and improved standards.

What is the research plan? There are two thrusts in this research plan: service life prediction of polymer composites and service life prediction of concrete. Figure 2 shows how the polymer composite work is structured. The path to the overall goal of service life prediction of structural polymer composites is divided into three levels: unfilled polymers, filled polymers, and structural polymer composites, which contain fibers and fillers. The unfilled polymer level was finished some years ago, and serves as the basis for 2nd and 3rd level work. The work on the second level in Fig. 2 on filled polymers is dealing with important new degradation mechanisms like mechanical movement, surface damage, electrical aging, and dispersion of fillers. When the fillers are nano-size, then their release during degradation becomes an important environmental-health-safety issue to be understood, and is also an active process in structural polymer composites with nanofillers. Inroads are now being made into the third level, based on all the research that has gone before in level one and that is still on-going in level two, on the effect on polymer composites of fatigue, water, adhesion between fiber and polymer matrix at the interface, and the effect of combinations of environmental factors. As research progresses up these levels, partners are identified who are helping the work progress while at the same time helping to identify and solve important national problems (see Impacts).

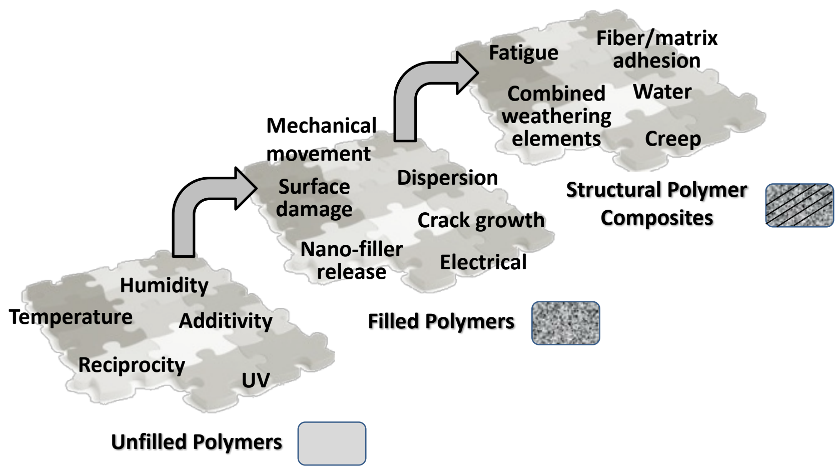

Figure 2: Structure of Service Life Prediction of Polymer Composites research

Figure 3 shows the overall structure of the service life prediction of concrete thrust, where its two levels reflect properties and performance. Previous work, some of it still on-going,

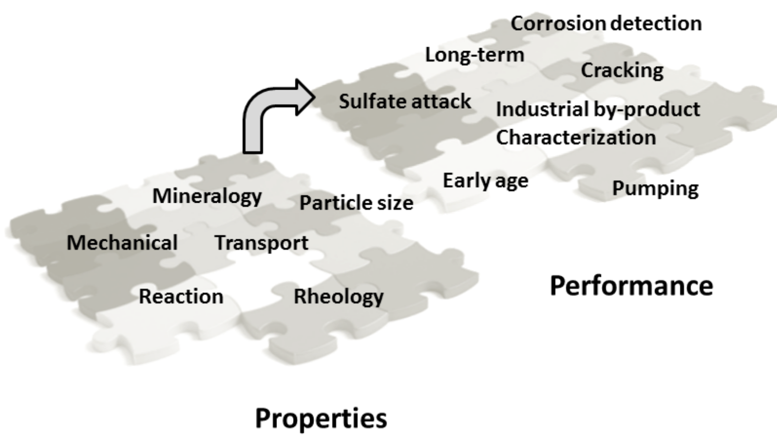

Figure 3: Structure of Service Life Prediction of Concrete research

concentrated on being able to characterize, measure and predict, with computational materials science models, various material properties of concrete at the cement paste, mortar, and concrete scales. This work has given the basis for looking at performance, in particular service life prediction, which encompasses both early-age and long-term performance, since concrete failures occur from mixing and placement to late-age degradation.

Characterization, performance measurement techniques, accelerated durability tests, and modeling will be used to achieve program goals. Characterization means measuring what the materials are made out of at the most relevant length scale. Measurement techniques mean quantitative measurements of properties such as viscoelastic mechanical parameters, shrinkage or expansion as a function of temperature or humidity, and surface damage under nanoindentation, among others. Accelerated durability tests can include carefully controlling temperature, humidity, solar exposure, mechanical load, or specimen geometry in order to make degradation mechanisms proceed faster and produce valid results in less time. Modeling is used, from the computational materials science-type models using high-powered computers to simple parameterized equations, to understand measurements, suggest new measurements, and transform performance measurements into performance predictions. Incorporating research results into standards, following the program's standards strategy, is the final step in the research plan. What is supplied to the standards committees can be in several forms: (a) standard reference data or materials, (b) new standard performance test methods, and (c) validation of the use and uncertainty estimation of a simpler tool by more sophisticated measurements.

How will teamwork be ensured? The Sustainable Engineered Materials program is made up primarily of members of EL's Polymeric and Inorganic Materials Groups, along with a NIST Fellow. There is a single principal investigator assigned for each of five projects who is accountable for the performance of the project. There is a team assigned to each project as well, who will interact regularly on project tasks. Each team member is the best qualified for the project(s) to which they are assigned. All the project leaders are accountable to the program manager, who reviews their progress periodically.

What is the impact if successful? The technical areas being worked on in this program have been jointly identified with industry and other end-users, hence the standards produced that meet identified needs will be adopted and used. Potential future impacts lie in the use of new and improved standards that will enable quantitative service life prediction for classes of concrete and polymer composites so that these materials can be manufactured and used in industry and infrastructure with assured early-age and long-term sustainable performance.

Many specific stakeholders and end-users from the broad communities of infrastructure and manufacturing have expressed keen interest in the program via intellectual and/or financial collaboration with individual projects: electric power industry and utilities, construction and infrastructure materials specifiers, electrical cable manufacturers and users/owners, coatings and plastics suppliers, automotive industry, aerospace industry, state Departments of Transportation, Nuclear Regulatory Commission, American Association of State Highway Transportation Officials (AASHTO), Gas Technology Institute (GTI), Adhesive and Sealant Council (ASC), and Plastic Pipes Institute (PPI).

<u>Program Impacts to date include the following</u>:

FY2012

- All the weathering standards for sealants and building joints in ASTM C24 Building Joints and Sealants have been changed to include mechanical movement. "Weathering" in this committee now is defined as having a mechanical movement component, a key variable in service life prediction, solely due to the measurement science research of this program.
    - ASTM 1735-11 *Test Method for Measuring the Time-Dependent Modulus of Sealants Using Stress Relaxation* and ASTM 1589-12 *Standard Practice for Outdoor Weathering of Construction Seals and Sealants* has passed.
- ASTM C1760-12 *Standard Test Method for Bulk Electrical Conductivity of Hardened Concrete* and ASTM C1585 Sorptivity Test Method, approved in FY12. These two documents standardize two key transport property measurements that are used in service life prediction.

- ASTM C1749-2012: *Standard Guide for Measurement of the Rheological Properties of Hydraulic Cementitious Paste Using a Rotational Rheometer*. First of a suite of standards that will allow the quantitative use of calibrated concrete rheometers.
- ASTM C1761-2012 *Standard Specification for Lightweight Aggregates for Internal Curing of Concrete*. Standardizes how to cure concrete to achieve low-cracking potential, giving more durable concrete.

Before FY2012

- NIST measurement science revealed that the time-dependent properties of the adhesive used in the Boston Harbor "Big Dig" disaster were neither considered nor sufficient to withstand long-term loading, which led to the new AASHTO standard "*Standard Test Method for Evaluation of Adhesive Anchors in Concrete Under Sustained Loading Conditions",* and to changes in the International Code Council (ICC) Evaluation Service AC308 document (http://www.icc-es.org/criteria/pdf_files/ac308.pdf) which now requires sustained loading testing for anchors adhered to concrete.
- The Justice Department asked NIST to solve the problem of why certain polymeric body armor was failing. NIST measurement science determined that wearing conditions were prematurely degrading the armor polymer. The protocols developed formed the basis of a new National Institute of Justice body armor service life standard 0101.06.
- The program developed ASTM C1365 - 06 *Standard Test Method for Determination of the Proportion of Phases in Portland Cement and Portland-Cement Clinker Using X-Ray Powder Diffraction Analysis* (2006). It is being used extensively in the US and Canada. NIST Standard Reference Materials SRM 2686/7/8 were developed by the program to support the use of this standard.
- The Underwriter's Laboratories (UL) and its customers want to modify their thermal aging of polymers standard, UL 746B, by incorporating the effects of relative humidity, radiation, and mechanical load into their product testing, leading them to the program's SPHERE technology. UL plans to adopt this measurement technology via a collaboration with NIST. UL has an enormous influence on standards involving the performance of polymer products (20B per year are UL-stamped).
- NIST Standard Reference Materials SRM 114Q/46H have been issued and are sold and used in the US, Canada, and Europe. These are cements used by laboratories for validating their use of two critical quality control tests for cement production and use involving particle fineness for short-term performance. Their combined sales of rank 3rd overall at NIST in the number of units sold.

What is the standards strategy? The main standards strategy of the program is to introduce research results into the proper technical committee in the most relevant standards development organizations (SDOs) to develop and improve needed standards. Most of the present-day materials standards targeted by program research do not allow performance prediction by those who are most interested in short and long-term performance – the end-users. Program members regularly participate as credible, honest brokers by presenting valid program measurement science research results that have been documented in peer-reviewed scientific literature. Leadership positions in these committees are sought, in order to increase NIST effectiveness in developing standards in collaboration with other committee members. NIST SRMs and Standard Reference Data (SRD) are developed as needed to support the use of the program's standards output.

When the need warrants, as an alternate standards strategy, program personnel participate in meetings involving multiple SDOs in order to accelerate identification of standards needs across an industrial sector. An example of this is the on-going Nuclear Energy Standards and Codes Committee (NESCC) effort, where a number of SDOs have come together in various technical committees to identify standards update and/or development needs for new nuclear power plant construction. NIST program personnel chair the technical task groups.

For concrete, the main external standards bodies are the American Society for Testing Materials (ASTM), the American Association of State and Highway Transportation Officials (AASHTO), and the American Concrete Institute (ACI). The most important SDO for general polymeric materials applications is ASTM. There are other, more specialized SDOs that focus on the performance of specific products made from polymers and polymer composites. Two examples of these bodies are the Underwriter's Laboratories (UL, plastic products), and the American Society of Mechanical Engineers (ASME, pipes and pressure vessels). The material standards developed in this program are expected to be used to guide manufacturers[24] and by designers to specify performance in order to assure more sustainable materials performance.

Top standards development needs for the program include:

- New fly ash classification scheme in ASTM C618 (by FY2016).
- ASTM standards in polymer sealant durability and surface damage of coatings and nanocomposites.
- ASTM standards to complete and implement the practical metrology of concrete rheometry for workability, to be used by industry and specifiers (by FY2015).
- New ASTM E56.03 test method for nanoparticle release from polymer nanocomposites as a function of weathering (by FY2014).
- Extensive revision of the UL thermal aging testing program using program technology, as requested by UL (by FY2015).
- Program leadership in the Nuclear Energy Standards Coordination Committee serving to complete reports summarizing standards needs in concrete, plastic pipes, and polymeric electrical cable insulation (by FY2013).
- A suite of performance-based durability standards to support the transition of specifiers and industry from prescriptive to performance-based concrete standards (by FY2016), which is also a certified measurement need.

Expected standards to be adopted over the next five years:

- **Passed in FY2012:** ASTM C1735-11: *Standard Test Method for Measuring the Time-Dependent Modulus of Sealant Using Stress Relaxation*, which will give industry an accurate way to characterize critical mechanical properties of sealants.

[24] *Special report: Manufacturing and Innovation: A third industrial revolution*, April 21, 2012 issue of *The Economist,* pp. 3-20.

- **Passed in FY2012:** ASTM C1749: *Standard Guide for Measurement of the Rheological Properties of Hydraulic Cementitious Paste Using a Rotational Rheometer*, which is foundational to the later concrete rheology standard.
- FY2013: Implement program research to revise ASTM D7187 standard on using nanoscratching to measure scratch/mar behavior of coatings.
- **Passed in FY2012**: ASTM C1760-12 *Standard Test Method for Bulk Electrical Conductivity of Hardened Concrete*, which is a rapid, simple concrete conductivity test in ASTM C09.66.
- FY2013 Issue of SRM for mortar rheology.
- FY2014: New standard in ASTM C24 Building Joints and Sealants to measure the difference between cracking and chemical aging, completing the standardization process for durable sealants.
- FY2015 Issue of SRM for concrete rheology and calibration tools for vane rheometers to be used in new standards.
- FY2015: Extensive revision of UL standard 746: Thermal Aging, incorporating program measurement technology in collaboration with UL.
- FY2016: New performance-based concrete durability ASTM standard (s).

Standards and standard reference materials produced by the program in recent years (in addition to the six passed in FY2012, which were already listed in the Impacts section):

- ASTM C1738 *Standard Practice for High-Shear Mixing of Hydraulic Cement Pastes* (2011). This is foundational to the suite of standards being built up by the program for using rheology to measure concrete workability.
- NIST Standard Reference Material #2492 *Bingham Paste Mixture for Rheological Measurements* (2011). This is the first of three standard reference materials that will be produced to support suite of standards being built up by the program for using rheology to measure concrete workability.
- ASTM C1698 *Standard Test Method for Autogenous Strain of Cement Paste and Mortar* (2009). This is a key test method for indicating the tendency for a concrete to crack at early-age during curing, hence can be used as a screening test.
- ASTM E2584 *Standard Practice for Thermal Conductivity of Materials Using a Thermal Capacitance (Slug) Calorimeter* (2007). This test gives a standard method for measuring the thermal conductivity of cementitious materials used as fire-protective thermal barriers on structural steel in high-rise buildings.

How will knowledge transfer be achieved? The primary way that program knowledge and results will be successfully disseminated to end-users is via consensus standards based on program measurement science. Another way is via periodic road mapping workshops, as each part of the end-user community for the program helps to update program research directions. Consortia meetings are included in this, along with specialized workshops like the annual Computer Modeling Workshop. Setting the technical foundation for the standards, and also serving as an independent means of technology transfer, are archival journal articles and professional society state-of-the-art reports that present program research results.

Program Outcomes:

New in FY12

- Established a new phase of the CRADA-based Polymer Surface and Interface consortium. Members include Boeing, Eastman Chemical, CSM, and BYK.
- Invited to join in the US/Canada NanoRelease project, whose purpose is to develop standard methods to measure release of engineered nanomaterials from articles relevant to commerce.
- Joined the EU NanoGEM and Polynanotox projects to develop methodology and standard tests to quantify release of nanoparticles by weathering.
- Developed a protocol to expose polymer nanocomposites to UV radiation, collect, and measure (at sub-nanogram resolution) photo-induced quantity of nanoparticles released from nanocomposites as a function of UV dose. These data are used to verify a recently-developed kinetic-based model for nanoparticle release.
- Lafarge, the world's largest building materials company, with large US holdings, has entered into a Cooperative Research and Development Agreement (CRADA) with NIST to study the role of aggregate shape on flow in cement-based materials.
- The NIST-industry CRADA-based Consortium CRÈME = *Concrete Rheology: Enabling Metrology* was established, with members including FHWA, SIKA, and BASF.
- The NIST-led NESCC report entitled *Polymer Pipe Codes and Standards for Nuclear Power Plants*, is being officially incorporated into the ASME Roadmap document entitled "ASME Code development roadmap for high-density polyethylene pipe in nuclear service."
- The Department of Energy awarded the NIST Engineering and Information Technology Laboratories 22 million computer processor hours at Argonne National Laboratory to carry out large scale simulations of suspension flow in real concrete rheometer geometries.
- Draft ASTM standard test method "Measurement of Mass Loss versus Time for One-Dimensional Drying of Saturated Concretes" developed (ASTM Work Item #37029 in subcommittee 09.66).
- Developed advanced measurement tools for polymeric insulation in electrical cables by combining spectroscopic, microscopic, and electrical measurement techniques for characterization of polymer degradation under exposure to relevant environmental stressors.
- NIST collaboration with US Nuclear Regulatory Commission (NRC) was established for the development of condition monitoring methods for aging electrical cables in nuclear power plants.

Before FY12

- *NESCC Concrete Task Group (CTG) Concrete Codes and Standards for Nuclear Power Plants: Recommendations for Future Development* (2011). This report has started to be implemented by the American Concrete Institute.
- Design and fabrication of a novel specimen holder to retrieve particles released from a nanocomposite during UV exposure on the NIST SPHERE.
- Cumulative damage-based methodology and model for predicting outdoor performance under varying environmental stressors using accelerated laboratory exposure data, which will be used to link indoor vs. outdoor exposure data for a broad range of polymeric materials.
- Protocols for measuring dispersion of fillers ranging in size from nanometers to micrometers in polymer nanocomposites using light and neutron scattering.

- Novel electric force microscopy technique and associated analytical models for quantitative surface and subsurface imaging of buried nanoparticles in polymer nanocomposites.
- *Measurement Science Roadmap for Workability of Cementitious Materials* held at NIST on March 18, 2011. The results of the workshop, officially issued as a NIST publication, were used as a guide for the program's concrete rheology work.
- VERDICT technology developed at NIST. This technology is a completely different way of enabling significant increases in the lifetime of concrete using a NIST discovery that makes concrete resistant to attack by aggressive, degrading chemicals like road salts.
- Continuing education website established at the Engineering News Record Continuing Education Center by TXI Expanded Shale & Clay in response to collaboration with program research, allowing the program's concrete curing results to be widely accessible.

Recognition of EL: There have been many articles in industry trade journals such as *Concrete Producer*, *Constructor*, *Stone Sand and Gravel Review*, *Legacy*, *Adhesives Age*, and *Journal of Coating Technology*, covering program research. In addition, articles about program research have appeared in *R&D Magazine*, *Engineering News Record*, *Concrete International*, *MIT Technology Review*, the *New York Times*, and the *Baltimore Sun*.

<u>New awards in FY2012</u>
Tinh Nguyen and Lipiin Sung, NIST Bronze Medal, 2011.
Jeffrey Bullard, American Ceramic Society Cements Division, Stephen Brunauer Award, 2012.
Jeffrey Bullard, Engineering Laboratory Communicator's Award, 2012.
Stephanie Watson, NIST Safety Award, 2012.
Dale Bentz, Best Paper Award, Magazine of Concrete Research, 2012.
Dale Bentz, Honorary member of ASTM C01 Cements committee.
Edward Garboczi, Della Roy Lecture, American Ceramic Society Cements Division, 2012.

<u>Awards that have been given to program personnel since 2007</u>:
Tinh Nguyen, American Coatings Association, Joseph J. Mattiello Award, 2010; Robert L. Patrick Fellow of the Adhesion Society, 2010.
Edward Garboczi, Nicos Martys, Jeffrey Bullard, and Dale Bentz, Department of Commerce Silver Medal, 2009.
Joannie Chin, Department of Commerce Gold Medal, 2010.
Aaron Forster, Adhesion Society Outstanding Young Adhesion Technologist, 2010.
Clarissa Ferraris, American Concrete Institute D.L. Bloem Distinguished Service Award, 2008
Walter Rossiter, ASTM S03 Award of Excellence, 2009; ASTM D08 William C. Cullen Award, 2008.
Edward Garboczi, NIST Fellow, 2009.
Christopher White, Department of Commerce, Bronze Medal 2009.
Chris White and Walt Rossiter, ASTM E54 Distinguished Service Award, 2009.
Dale Bentz and Kenneth Snyder, Department of Commerce Bronze Medal, 2009.
Paul Stutzman, ASTM P.H. Bates Award, 2008; Department of Commerce Bronze Award, 2007.
Dale Bentz, Expanded Shale, Clay & Slate Institute Frank G. Erskine Award. 2007; American Concrete Institute Wason Medal for Materials, 2007.